

**What is claimed is:**

1        1. A method for I/Q imbalance calibration of a  
2 transmitter, comprising the steps of:  
3        initializing parameters  $A_p$ ,  $B_p$  and  $\gamma_p$ ;  
4        estimating a loop delay factor  $L$ ;  
5        generating a test signal  $x[n]=x(n \cdot T_s)$ , wherein  $x(t)=e^{j\omega_T t}$   
6                and  $\omega_T$  is a preset radian frequency and  $T_s$  is  
7                sampling interval;  
8        generating a compensated signal  $x_{com}[n]$  by compensating  
9                the test signal  $x[n]$  according to a first  
10                function with parameters  $A_p$ ,  $B_p$  and  $\gamma_p$ ;  
11        converting the compensated signal  $x_{com}[n]$  to an analog  
12                signal  $x_{com}(t)$ ;  
13        applying I/Q modulation to the analog signal  $x_{com}(t)$  and  
14                outputting a modulated signal  $x_{mod}(t)$ ;  
15        obtaining a characteristic signal  $x_c(t)$  of the  
16                modulated signal  $x_{mod}(t)$ ;  
17        obtaining a sampled characteristic signal  $x_s[n]$  by  
18                sampling the characteristic signal  $x_c(t)$  and  
19                obtaining statistics  $U_1$  and  $U_2$  of the sampled  
20                characteristic signal  $x_s[n]$ , where  $U_1$  and  $U_2$  are  
21                values indicative of the frequency response of  
22                 $x_c(t)$  at radian frequency  $\omega_T$  and  $2\omega_T$ ,  
23                respectively; and  
24        updating the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$  respectively by  
25                one of the second functions, the loop delay  
26                factor  $L$ , the statistics  $U_1$  and  $U_2$ , and the  
27                current values of the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$ .

1           2.    The method as claimed in claim 1, wherein the step  
2 of estimating the loop delay factor further comprises the  
3 steps of:

4           generating a test signal  $x'[n]=\cos(\omega_T n T_s)+\gamma_T$  which is a  
5           discrete-time signal and  $\gamma_T$  is a predetermined  
6           number;

7           converting the test signal  $x'[n]$  to an analog signal  
8            $x'(t)$ ;

9           applying I/Q modulation to the analog signal  $x'(t)$  and  
10          outputting a modulated signal  $x'_{\text{mod}}(t)$ ;

11          obtaining a characteristic signal  $x'_c(t)$  of the modulated  
12          signal  $x'_{\text{mod}}(t)$ ;

13          obtaining a sampled characteristic signal  $x'_s[n]$  by  
14          sampling the characteristic signal  $x'_c(t)$  and  
15          obtaining a statistics  $V$  of the sampled  
16          characteristic signal  $x'_s[n]$ , where  $V$  is a value  
17          indicative of the frequency response of  $x'_c(t)$  at  
18          radian frequency  $\omega_T$ ; and

19          estimating the loop delay factor  $L$  based on the  
20          statistics  $V$ .

1           3.    The method as claimed in claim 2, wherein the  
2 statistics  $V$  is obtained by taking FFT of the sampled  
3 characteristic signal  $x'_s[n]$ .

1           4.    The method as claimed in claim 3, wherein the  
2 estimated loop delay factor  $L$  is  $V/|V|$ .

1           5.    The method as claimed in claim 1, wherein the  
2 first function is  $x_{\text{com}}[n]=A_p \cdot x[n]+B_p \cdot x^*[n]-\gamma_p$ .

1        6. The method as claimed in claim 1, wherein the  
2 statistics  $U_1$  and  $U_2$  are obtained by taking FFT of the  
3 sampled characteristic signal  $x_s[n]$ .

1        7. The method as claimed in claim 1, wherein the  
2 parameters  $A_p$ ,  $B_p$  and  $\gamma_p$  are updated by the steps of:  
3        computing the updated  $A_p$  based on the current  $A_p$  and  $B_p$ ,  
4        the loop delay factor  $L$ , and the statistic  $U_2$ ;  
5        computing the updated  $B_p$  based on the current  $A_p$  and  $B_p$ ,  
6        the loop delay factor  $L$ , and the statistic  $U_2$ ;  
7        and  
8        computing the updated  $\gamma_p$  based on the current  $\gamma_p$ , the  
9        loop delay factor  $L$ , and the statistic  $U_1$ .

1        8. The method as claimed in claim 1, wherein the  
2 second functions for updating the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$   
3 are:

4         $A'_p = A_p - \mu \cdot B_p \cdot U_2^* \cdot L \cdot L$  ;

5         $B'_p = B_p - \mu \cdot A_p \cdot U_2 \cdot (L \cdot L)^*$  ; and

6         $\gamma'_p = \gamma_p + \mu \cdot U_1 \cdot L$  ;

7        where  $A'_p$ ,  $B'_p$  and  $\gamma'_p$  are the updated values,  $A_p$ ,  $B_p$  and  
8         $\gamma_p$  are the current values, and  $\mu$  is a preset step  
9        size parameter.

1        10. The method as claimed in claim 1, wherein the  
2 characteristic signal is derived by taking the square of an  
3 envelope of the modulated signal.

1        11. The method as claimed in claim 2, wherein the  
2 characteristic signal is derived by taking the square of an  
3 envelope of the modulated signal.

1        12. An apparatus for I/Q imbalance calibration in a  
2 transmitter comprising:

3        a discrete-time signal generator generating a first  
4            test signal  $x_1[n]=\cos(\omega_T n T_s)+\gamma_T$ , where  $\omega_T$  is a preset  
5            radian frequency,  $T_s$  is a predetermined sampling  
6            interval, and  $\gamma_T$  is a predetermined number, in an  
7            estimation phase, and generating a second test  
8            signal  $x_2[n]=e^{j\omega_T n T_s}$  in a calibration phase which  
9            follows the estimation phase;

10       a correction module receiving the test signal from the  
11            signal generator, compensating the test signal  
12            according to a first function with parameters  $A_p$ ,  
13             $B_p$  and  $\gamma_p$  to produce a compensated signal;

14       a first and second D/A converter converting the  
15            compensated signal to an analog signal, wherein  
16            the first D/A converter converts the real part of  
17            the compensated signal to the real part of the  
18            analog signal, and the second D/A converter  
19            converts the imaginary part of the compensated  
20            signal to the imaginary part of the analog  
21            signal;

22       a modulator applying I/Q modulation to the analog  
23            signal, and outputting a modulated signal;

24       a detector obtaining a characteristic signal of the  
25            modulated signal;

26       an A/D converter converting the characteristic signal  
27            to a sampled characteristic signal; and

28       a processor implementing the steps of:

29            initializing the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$ ;

30 obtaining a statistic  $V$  based on the sampled  
31 characteristic signal in the estimation  
32 phase, where  $V$  is a value indicative of the  
33 frequency response of  $x_c'(t)$  at radian  
34 frequency  $\omega_T$ ;  
35 estimating a loop delay factor  $L$  based on the  
36 statistic  $V$  in the estimation phase;  
37 obtaining statistics  $U_1$  and  $U_2$  based on the  
38 sampled characteristic signal in the  
39 calibration phase, where  $U_1$  and  $U_2$  are values  
40 indicative of the frequency response of  
41  $x_c(t)$  at radian frequency  $\omega_T$  and  $2\omega_T$ ,  
42 respectively; and  
43 updating the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$  based on the  
44 loop delay factor  $L$ , the statistics  $U_1$  and  
45  $U_2$ , and the current values of the parameters  
46  $A_p$ ,  $B_p$  and  $\gamma_p$  in the calibration phase.

1 13. The apparatus as claimed in claim 12, wherein the  
2 statistics  $V$  are obtained by taking FFT of the sampled  
3 characteristic signal in the estimation phase.

1 14. The apparatus as claimed in claim 12, wherein the  
2 loop delay factor  $L$  is  $V/|V|$ .

1 15. The apparatus as claimed in claim 12, wherein the  
2 first function is  $x_{com}[n] = A_p \cdot x[n] + B_p \cdot x^*[n] - \gamma_p$ , where  $x[n]$  and  
3  $x_{com}[n]$  denote the test signal and the compensated signal,  
4 respectively, and  $x[n] = x_1[n]$  in the estimation phase,  $x[n] =$   
5  $x_2[n]$  in the calibration phase.

1        16. The apparatus as claimed in claim 12, wherein the  
2 statistics  $U_1$  and  $U_2$  are obtained by taking FFT of the  
3 sampled characteristic signal in the calibration phase.

1        17. The apparatus as claimed in claim 12, wherein the  
2 processor updates the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$  by the steps  
3 of:

4        computing the updated  $A_p$  based on the current  $A_p$  and  $B_p$ ,  
5                the loop delay factor  $L$ , and the statistic  $U_2$ ;  
6        computing the updated  $B_p$  based on the current  $A_p$  and  $B_p$ ,  
7                the loop delay factor  $L$ , and the statistic  $U_2$ ;  
8                and  
9        computing the updated  $\gamma_p$  based on the current  $\gamma_p$ , the  
10                loop delay factor  $L$ , and the statistic  $U_1$ .

1        18. The apparatus as claimed in claim 17, wherein the  
2 processor updates the parameters  $A_p$ ,  $B_p$  and  $\gamma_p$  by the  
3 equations::

4         $A'_p = A_p - \mu \cdot B_p \cdot U_2^* \cdot L \cdot L$  ;  
5         $B'_p = B_p - \mu \cdot A_p \cdot U_2 \cdot (L \cdot L)^*$  ; and  
6         $\gamma'_p = \gamma_p + \mu \cdot U_1 \cdot L^*$

7        where  $A'_p$ ,  $B'_p$  and  $\gamma'_p$  are the updated values,  $A_p$ ,  $B_p$  and  
8                 $\gamma_p$  are the current values, and  $\mu$  is a preset step  
9                size parameter.

1        19. The apparatus as claimed in claim 12, wherein the  
2 characteristic signal is derived by taking the square of an  
3 envelope of the modulated signal.